Ordinarily, photometry is done as close to the meridian as possible to mitigate the error introduced by scintillation and rapid extinction variations that are associated with high air mass. For this reason, measurements are usually made at an air-mass less than 1.5 and seldom are made at an air mass as large as 2.0. However, to obtain the data on November 22, the measurements were made as the air mass ranged from 1.5 to 4. Figure 2 shows the measured rapid increase in standard deviation (SD) of the fluxes of the seven comparison stars at the time of the measurements. The solid curve shows the expected level of scintillation noise. The agreement between these measurements and the predictions of the scintillation noise demonstrates that the system was operating at a precision limited only by properties of the atmosphere. The observations were terminated at an air mass of 4 because the signal-to-noise ratio had dropped below 2.5 at that point.

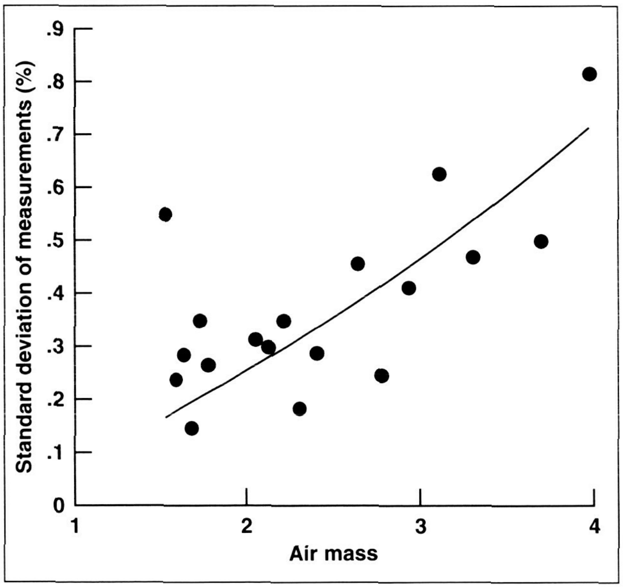

Fig. 2. Comparison of the standard deviation of the fluxes of the comparison stars with the prediction of scintillation noise by Young (1974).

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Planetary Rings

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In addition to the natural curiosity inspired by their unusual appearances, planetary rings present a unique dynamical laboratory for understanding the properties of collisional particle disks that might help us understand the accretion of the planets. Ames maintains the Planetary Data System's Rings Node (http://ringmaster.arc.nasa.gov/), which archives and distributes ring data from NASA's spacecraft missions and from Earth-based observatories. The entire archive of images from the Voyager missions to the giant planets is now available on line, with catalogs to help users find the images they need. All the images of Saturn obtained by the Hubble Space Telescope (HST) during 1995, when the rings were seen edge-on to Earth, are available.

An important theoretical advance was taken in the development of a new theory for how narrow, elliptical rings, with nested elliptical orbits, preserve their shape over long periods of time in the face of the tendency of their inner orbits to precess more rapidly than their outer orbits, causing misalignment and collisional disruption. The major previous theory relied exclusively on ring self-gravity to provide the slight counteracting force needed to prevent this precession, but the mass implied was much smaller than that believed to lie in these rings based on other observations. This year, new physics was added to the equations of motion in the form of pressure tensors in dense particle layers that behave like traffic jams. The new physics, in fact, makes it more difficult for self-gravity to maintain the alignment of the nested orbits, and boosts the needed mass density into much better agreement with observations.

New observational results were also obtained from analysis of extensive HST observations of Saturn's rings, taken over the last three years as the ring opening angle increased as seen from the Earth and the Sun (figure 1). Taken in eight different colors (several not observable from Earth), these new observations show for the first time that the ring brightness varies with phase angle but not with ring opening angle. This finding makes it clear that the reflectivity is caused by multiple scattering within a granular regolith on large ring particles, but not between ring particles. This result led to the

Fig. 1. Typical HST images of Saturn's rings at two different opening angles. The spatial resolution is adequate to easily resolve color and compositional differences between many different regions of the rings.

realization that the ring particles are less red than previously determined from Voyager observations at a higher phase angle. Furthermore, the HST data provide evidence for increased absorption by water ice in certain parts of the rings relative to others, indicating differences in either the surface coverage or surface grain size on the particles. Also, the optically thinner parts of the rings, where the particles have been known to be darker (its inner or C ring, and the Cassini division lying between the main A and B rings), reveal an unassigned absorption feature in the 850-nanometer spectral range. Tentative evidence for such absorption had been hinted at in earlier observations, but the new observations not only verify its existence, but also clearly show that the absorber is localized to the C ring and the Cassini division. A high-resolution HST image of Saturn's faint G ring that was obtained shows that the radial distribution of large particles is similar to that of tiny dust grains observed by Voyager and Galileo. The HST data are being used now in planning Cassini observations of Saturn that will begin in 2004.

Finally, new analyses of Voyager data show that the bright knots and clumps in the curious F ring of Saturn are transient. A few are seen to appear and then dissipate in a matter of days; these are probably caused by puffs of debris from impacts of meteoroids into the larger ring bodies. However, most clumps persist for a matter of months and are probably caused by the more gentle collisions among the bodies themselves. In addition, smaller ring clumps are periodic, showing the characteristic spacing that would be expected from gravitational interactions with the nearby "shepherding" moon Prometheus. Present dynamical models suggest that this periodic tug between the ring and moons may also give rise to a random component in Prometheus' orbit, as has been observed in recent HST images.

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